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CHANGES IN INDICES OF EXTERNAL RESPIRATION, GAS EXCHANGE AND ENERGY EXPENDITURES IN WEIGHTLESSNESS

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CHANGES IN INDICES OF EXTERNAL RESPIRATION, GAS EXCHANGE AND ENERGY EXPENDITURES IN WEIGHTLESSNESS 1*

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Prolonged space flights are related to exposure of the human organism to an entire set of adverse factors, including weightlessness. The numerous studies of the last few years indicate the possible appearance of substantial changes in various systems of the organism under conditions of weightlessness [1, 2, 3, 4, 5, 6, 7, 8, 9].

The changes in function of different systems caused by the unaccustomed weightlessness may elicit specific changes in metabolism and thermal balance of the organism which as a whole will affect the cosmonaut's efficiency.

The study of the influence of weightlessness on the organism, problems of adaptation and compensation are intimately related to the study of gas exchange as an integrative index of the functional state of the organism. It is known that gas exchange reflects as a whole the dynamics of changes occurring in it. The problem of creating optimum conditions with respect to gas environment both in the cabins of flying machines where man will perhaps be part of a closed ecological system of circulation of substances [1, 11] and in space suits when the cosmonaut works in open space, requires knowledge of the mean and optimum values of oxygen consumption and carbon dioxide excretion.

The study of gas exchange is important to solve a number of theoretical, practical and prognostic problems in cosmonautics. 2

At the present time there are not enough scientifically substantiated data in the literature on the basis of which it would be possible to determine metabolic expenditures in weightlessness.

In the opinion of some researchers [12, 13, 14] performance of working operations in weightlessness is related to excessive energy expenditures elicited by the new conditions. Ch. Berry (1966)[14] reported that the mean energy expenditures of the astronauts in the Gemini 9 and 10 flights constituted 91.7-94.4 large calories per hour. He stresses that in the opinion of most American astronauts (Gemini 4, 9, 10, 11) it is four times more difficult to perform work in outer space than in a pressurized suit on Earth.

According to the theoretical estimates of other authors [8, 16, 15] the metabolic changes will be within physiological range in weightlessness lasting from a few minutes to a few hours.

*Numbers in the margin indicate pagination in the original foreign text.

A.M. Genyan et al (1965) [17], on the basis of analysis of the results of postflight processing of regeneration substances and dynamics of changes in concentrations of oxygen, carbon dioxide and H_2O in the air of spacecraft cabins, concluded that space flight conditions do not have an appreciable influence on human energetic expenditures. According to their data, the mean expenditure of energy per hour during such flights constituted: 85.8 large calories for A.G. Nikolayev, 97.2 for P. R. Popovich, 83.5 for V.V. Tereshkova, and 84.6 large calories per hours for B.F. Bykovskiy. In their opinion a drop of basal metabolic indices 3
will be observed with prolonged space flights.

In the present article are submitted data (1963-1966) on the functional state of external respiration, gas metabolism and energetic expenditures of man during brief weightlessness simulated by parabolic flight in a laboratory-airplane.

The following were recorded on the subjects during flight: respiration rate, vital capacity of the lungs, pulmonary ventilation and samples of exhaled air were collected. The tests were made by the conventional Douglas-Holden method as well as with the use of small spiroanemometers, Reseda-2 and 3 which have an attachment for collecting exhaled air which is then analyzed on a Holden machine. Volumetric conversions from the gas exchange were performed under STPD conditions, and those from external respiration -- BTPS.

In the three series of experiments a total of 58 flights were made with the participation of 55 subjects ranging in age from 22 to 46 years.

In the first series of experiments (7 flights) the subjects remained in a chair throughout the flight. As demonstrated by the results, during the period of brief weightlessness all of the subjects presented the highest level of gas metabolism as compared to initial levels. It was also above the level obtained during flight with exposure to accelerations. The data on gas metabolism and energetic expenditures during parabolic flight are given in Table 1.

As shown in the table, minute oxygen consumption increased during 5
weightlessness as compared to the initial level, by 75-215 ml [milliliters]; energetic expenditures increased accordingly by 0.36-1.0 large calories per minute; minute volume of respiration was 0.4-4.2 liters/minute higher in six experiments and 0.3 liters/minute higher in one, as compared to the initial data.

In the second series of experiments conducted using the Reseda-2 spiroanemometer, 36 flights were made, 21 of which involved collection of inhaled air samples. In these experiments, along with study of external respiration, gas metabolism and energetic expenditures with the subjects at relative rest (nine flights), there were seven flights with a measured physical load and five with performance of purposeful working operations (the work corresponded to 100.8 kilogrammeters).

Table 1
[beginning of caption is cut off in source]...rest during parabolic flight in laboratory-airplane (by the Douglas Holden method)

Subject	flight No	minute volume, liters/minute*			oxygen consumption, ml/minute**			energy expenditures large calories/minute		
		initial data	weightless-ness	accele-ration	initial data	weightless-ness	accele-ration	initial data	weight-less-ness	accele-ration
B-v	18	9.5	13.7	9.1	320	533	326	1.54	2 54	1.57
N-v	23	7.9	10.3	8.5	300	383	314	1.43	1.84	1.49
Sh-ts	15	9.4	10.8	9.6	337	428	368	1.58	2.05	1.76
Sh-ts	16	9.5	9.2	8.2	292	391	333	1.40	1.87	1.61
Sh-ts	18	9.2	9.9	8.3	277	352	304	1.34	1.80	1.50
D-v	3	9.4	11.4	8.8	280	393	300	1.35	1.91	1.46
B-v	25	9.1	10.8	9.5	279	395	308	1.33	1.86	1.47

Footnotes:
* - calculation made in accordance with BTPS conditions
** - calculation made in accordance with STPD conditions

Table 2 submits the indices of gas metabolism of the subjects 5
in a state of relative rest (seated) during brief weightlessness, and during the horizontal segment of flight (background data).

As shown in Table 2, in all of the experiments of the second series as in the first, in weightlessness there were higher indices of gas exchange than during horizontal flight. Thus, minute oxygen consumption in weightlessness was 32-238 ml higher than the initial data, while energy consumption was 0.16-1.08 large calories per minute greater.

Statistical analysis of the data obtained from 24 flights (Table 3) revealed that pulmonary ventialtion in brief weightlessness was higher than during horizontal flight by 4.6 liters per minute, respiration rate
increased by 2.1 cycles per minute; vital capacity of the lungs increased 7
by 400 ml; It was also observed that there was a change in the respiratory cycle in weightlessness.

A study of gas metabolism in the subjects while performing physical exertion (Figure 1) revealed that as compared to the same work performed during horizontal flight, in weightlessness work elicited more marked changes in indices of external respiration, gas exchange and accordingly greater energy consumption. While pulmonary ventilation increased by an average of 4.6 liters per minute in weightlessness (I), when performing a measured amount of physical work (II) it increased by 11.7 liters per minute, and when performing purposeful working operations -- by 16.8 liters per minute (III). Oxygen consumption in weightlessness increased as follows: by 134 ml/minute at relative rest, by 185 ml/min when performing measured physical work, and by 291 ml/min when performing working operations. There was more energy expended in weightlessness than during the horizontal segment of flight: by a mean of 39 calores per hour at rest, by 55 calores per hour with measured physical work, and by 83.4 calories per hour with performance of working operations. It is important to mention the considerable individual fluctuations in brief weightlessness with respect to the same physical load. Even in the same subject, the amount of energy expended varied from one hill to the other, from one flight to another. It was established that there was visible fluctuation in energy expended for the same activity, depend-
ing on age, weight, training and intensity of the working operations per- 8
formed.

It must be stressed that during performance of work in special clothing [space suit] the changes in gas exchange and energy expenditure were even more marked. For example, in subject S-n, when working in ordinarly clothing pulmonary ventilation rose by 17.1 liters per minute during wieghtlessness as compared to the same work during horizontal flight; when working in a space suit, the increase constituted 22 liters per minute. In the former case, oxygen consumption increased by 207 ml/minute, in the latter -- by 533 ml/minute. Energetic expenditure increased by 83 and 153 large calories per hour, respectively.

Table 2

Oxygen consumption and energetic expenditures of subjects in a state of relative rest at different periods of parabolic flight (according to Reseda-2 data)

Subjects	Oxygen consumption, ml/minute			energetic expenditures, large cal/minute		
	preflight	weightlessness	difference	preflight	weightlessnes	difference
V-o	274	306	+32	1.32	1.48	+0.16
G-n	254	432	+178	1.21	2.14	+0.93
G-v	330	594	+219	1.54	2.62	+1.08
Zh-v	227	465	+238	1.12	2.20	+1.08
K-yan	214	325	+111	1.07	1.61	+0.54
K-in	233	434	+201	1.15	2.09	+0.94
K-yan	230	252	+22	1.09	1.19	+0.10
K-yan	256	283	+27	1.22	1.33	+0.11
K-yan	366	564	+180	1.77	2.65	0.88

Note: calculation made in accordance with STPD conditions.

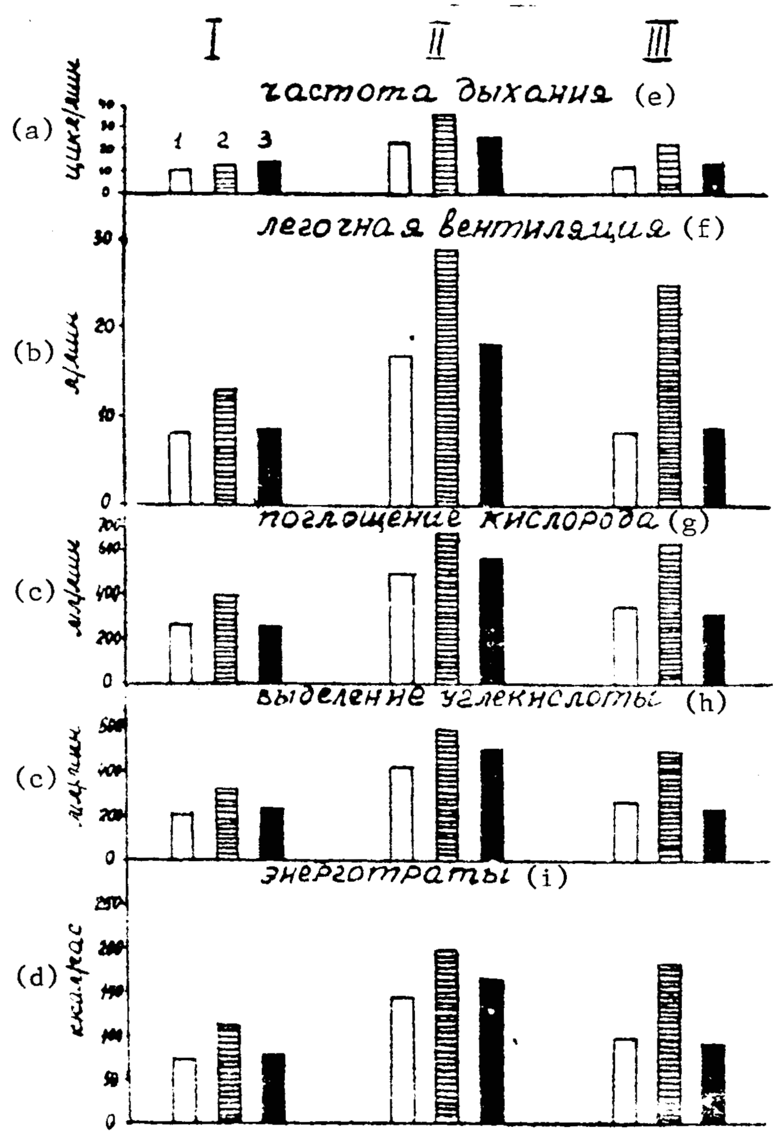

Figure 1. Changes in indices of external respiration, gas exchange and energy expended in subjects at relative rest (I), during measured physical exertion (II) and during performance of working operations (III)

Legend:

1) horizontal flight
2) weightlessness
3) after flight
a) cycles per minute
b) liters per minute
c) ml/minute
d) large calories per hour
e) respiration rate
f) pulmonary ventilation
g) oxygen consumption
h) carbon dioxide excretion
i) energy expended

Table 3 8

Changes in some indices of external respiration of subjects at relative rest during aircraft flight in a Kepler parabola (according to data of the Reseda-2 instrument)

Statistical indices		External respiration indices: minute volume liters/minute	respiration rate cycles/minute	vital capacity milliliters
Arithmetic mean M+m (24 cases)	preflight	8.0±2.19	11±2.79	3000±436
	weightlessness	13.0±2.72	13±3.76	4200±702
Difference between means (Xm) and error in difference (m diff) before flight and in weightlessness		4.65±0.534	2.1±0.65	400±98.4
Criterion of reliability of differences (t)		8.7	3.3	5.2
Probability (P)		0.001	0.01	0.001

Note: calculation made as applied to BTPS conditions

In the third series of experiments (15 flights) conducted with 10
the use of the Reseda-3 spiroanemometer energy expended by the subjects was estimated by the magnitude of pulmonary ventilation (according to the Ford and Hellerstein (1959) formula.

Analysis of the results of these experiments revealed that the greatest changes in respiration rate, pulmonary ventilation and energetic expenditure, as in the experiments of the preceding series, were noted in the subjects during brief weightlessness (Table 4). Thus, as compared to the initial data, pulmonary ventilation increased on an average of 11.15 to 11.51 liters/minute during the horizontal segment of flight, to 12.92 liters/minute during exposure to accelerations, to 14.18 liters per minute in weightlessness. Energy expenditures increased from 2.35 to 2.50 calories per minute in horizontal flight, to 2.75 with accelerations and to 2.98 large calories per minute in weightlessness.

Thus, the results are indicative of the identity of changes in external respiration, gas exchange and expended energy in the subjects during weightlessness, regardless of the examination method used.

Table 4 9

Respiration rate, pulmonary ventilation and energy expenditure in subjects during flight along Kepler's parabola (according to data from the Reseda-3 instrument)

	Statistical indices		
	M	ς	C%
Initial data:			
respiration rate	10.3	2.18	24.2
pulmonary ventilation	11.15	3.13	28.14
energy expenditures	2.3576	0.5701	23.2
Horizontal flight:			
respiration rate	9.7	3.56	36.4
pulmonary ventilation	11.51	2.78	24.2
energy expenditures	2.5095	0.7746	33.1
Accelerations:			
respiration rate	10.4	3.30	31.8
pulmonary ventilation	12.92	3.43	26.9
energy expenditures	2.7517	0.6000	21.8
Weightlessness:			
respiration rate	10.5	4.04	38.2
pulmonary ventilation	14.18	3.16	22.4
energy expenditures	2.9766	0.5385	18.2
Accelerations:			
respiration rate	10.4	3.17	30.5
pulmonary ventilation	13.15	4.27	32.5
energy expenditures	2.8036	0.7416	26.53
Horizontal flight			
respiration rate	10.2	3.20	31.6
pulmonary ventilation	11.28	30.68	32.7
energy expenditures	2.4779	0.6403	26.05

The higher intensity of gas exchange processes and higher energy 10
expenditures in weightlessness, as compared to horizontal flight and even accelerations, suggests that brief weightlessness has a considerable influence on the human organism. The energy expended by cosmonauts while working in space suits both in the capsules of spacecraft and particularly during extravehicular activity, will exceed significantly the energy expended for analogous work during brief weightlessness and on Earth.

For this reason it will be of prime importance to determine cosmonauts' energy expenditures while performing various work procedures during space flights. 11

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